RESPONSE OF SEVERAL WEED SPECIES TO LOW VOLUME GLYPHOSATE APPLICATION METHODS

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ABSTRACT

Various low volume applicators were evaluated for controlling several perennial weed species in Hawaii. White thunbergia (*Thunbergia fragrans* Roxb.), purple nutsedge (*Cyperus rotundus* L.), guava (*Psidium guajava* L.) and guineagrass (*Panicum maximum* Jacq.) were the weed species used. The wiper applicator (10% and 25% v/v) provided the best overall weed control. The Magicwand (5% and 10% v/v) and the brush applicator (5% and 10% v/v) provided similar control to that of the conventional application method (1% and 2% v/v). The failure of the Magicwand and brush applicator to provide better control of purple nutsedge and thunbergia than the conventional method was probably due to inadequate herbicide coverage. Guava was the most tolerant weed species; none of the plants were killed.

Glyphosate at rates of 0, 0.5, 1.0, 2.0 and 4.0 kg a.e./ha was applied in diluent volumes of 45, 90, 180 and 360 L/ha by the conventional method to the weed species listed above. Decreasing the diluent volume (360 L/ha to 45 L/ha) of a given glyphosate rate (usually the lower rates) caused an increase in glyphosate activity. Again, guava was the most tolerant of the 4 weed species.

A study was conducted to determine the effect of glyphosate (MON-0139; 0, 1, 2, 4% w/w) and surfactant (MON-0818; 0, 0.1, 1, 10% w/w) concentrations applied in different drop numbers to a specified leaf pair of

thunbergia and guava. For thunbergia, the experiment showed that 1-1 uL drop of a 4% w/w glyphosate solution was more effective in reducing shoot fresh weight than 4-1 uL drops of a 1% w/w glyphosate solution, but this was not reflected in regrowth shoot fresh weight. Addition of surfactant also enhanced glyphosate activity, but glyphosate concentration in the drop was the more important limiting factor. With guava, only visual ratings showed a result comparable to that of thunbergia. Other parameters did not reflect any trends. This was probably due to the high degree of tolerance of guava to glyphosate.

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CHAPTER I

INTRODUCTION

Glyphosate (N-(phosphonomethyl)glycine) is a systemic, non-selective herbicide with a high degree of activity. Hard to control annual and perennial weeds (having underground vegetative propagules) can be controlled with glyphosate.

The introduction of glyphosate in the early 1970's led to the development of several specialized herbicide applicators in the late 1970's. Until the development of such selective application equipment, glyphosate was restricted for use in non-crop areas or tree crop situations where glyphosate could be directed away from green bark tissues. Glyphosate can now be applied to selectively control weeds within the crop. Many applicators utilize the wiping technique using absorbant materials such as sponges, carpets and ropes. Other designs can be developed for particular situations. Higher concentrations of glyphosate are generally used (5 to 50% v/v), and the diluent volume is greatly reduced.

The objectives of this study are: (1) to evaulate the effectiveness of some low volume applicators on weed species with different growth habits, (2) to further support findings that low volume-high concentrate glyphosate applications are more active than high volume-low concentrate applications, (3) to determine what factor(s) may be responsible for the increased activity at the low diluent volumes.

CHAPTER II

REVIEW OF LITERATURE

Low Volume Herbicide Application Methods

Low volume herbicide application methods were developed to counter problems of drift and insufficient selectivity of foliar-applied postemergence herbicides. The use of recirculating sprayers and 'wipe-on' techniques have become widespread in the United States (72). Much of the research in the United Kingdom has been concentrated on controlled drop application (63).

The wipe-on methods of pesticide application were developed in the early 1900's as Mahanay (1909), Goode (1923), Hay (1929), Corley & Salley (1937) and Segars & Laniar (1940) applied insecticides to their crops using wicks, felt strips and mop filaments. The introduction of the phenoxy herbicides in the early 1940's prompted use of wipe-on methods to selectively apply herbicides to weeds growing taller than the crop (72).

Three categories of wipe-on equipment have been developed for selective application in the field; the ropewick applicator, the wiper and the roller.

Dale (20) developed the ropewick applicator to apply non-selective herbicides to weeds growing either above or below the crop canopy. The main components of the ropewick applicator are the wicks which convey the herbicide to the weeds by physically wiping the herbicide on, and the reservoir of herbicide solution in which the ends of the wicks are placed. The herbicide solution that is wiped onto the weeds is replenished from the reservoir by capillary action.

Glyphosate (N-(phosphonomethyl)glycine) was introduced by the Monsanto Company in 1971. It is a systemic, non-selective herbicide with a high degree of herbicidal activity (6). Glyphosate has been shown to interfere with the synthesis of aromatic amino acids (36).

Varying degrees of weed control have been reported with the use of glyphosate in the ropewick applicator. Dale (21) reported greater than 90% control of johnsongrass (Sorghum halepense (L.) Pers.) in soybeans (Glycine max (L.) Merr.) with an actual applied rate of 0.07 kg/ha glyphosate. Wiese and Lavake (70) obtained 100% control of silverleaf nightshade (Solanum elaegnifolium Cav.) in cotton (Gossypium sp.) using a 120 g/L glyphosate solution. Furrer et al. (31) concluded that ropewick-type applicators with a 120 g/L glyphosate solution can be used effectively for glyphosate application to shattercane (Sorghum bicolor (L.) Moench) and volunteer corn (Zea mays L.) in grain sorghum (Sorghum sp.). They also noted that double coverage with the ropewick applicator provided the best weed control (31, 32, 39). Miller et al. (46) obtained good weed control of several perennial weed species in established pasture and native rangeland using a 180 g/L glyphosate solution. In contrast, Peters and Dale (48) obtained only 50% control of late eupatorium (*Eupatorium* sp.) in pastureland with a 120 g/L glyphosate solution. Selleck et al. (58) found that using glyphosate rates as high as 180 g/L were ineffective on barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.). smartweed (*Polygonum pensylvanicum* L.) and lambsquarters (*Chenopodium album* L.) in a field of potatoes (*Solanum tuberosum* L.).

Picloram (4-amino-3,5,6-trichloropicolinic acid) and dicamba (3,6-dichloro-*o*-anisic acid) applied with the ropewick applicator were more effective on some weed species than glyphosate. Picloram performed better than glyphosate on late eupatorium (*Eupatorium* sp.) (48) and dicamba gave better control of woolyleaf bursage (*Franseria tomentosa* Gray) (38) and Texas blueweed (*Helianthus ciliaris* CD.) (70) than glyphosate.

Many factors may be responsible for the varied results obtained with the ropewick applicator. Poor control may be related to insufficient herbicide being wiped onto the weeds. Slow wicking action of the rope, dense weed stands and fast tractor speeds are some factors involved in poor coverage (72). Herbicide concentration is another important factor and dripping may be a problem (49).

Chandler (17) developed the Stoneville Wiper, an herbicide applicator that selectively wipes the herbicide onto weeds in the early stages of the crop. Good to excellent control of nutsedge (Cyperus sp.), annual grass (Poa sp.) and cocklebur (Xanthium sp.) was obtained with this applicator using glyphosate. Excellent control of many weed species growing taller than cranberry (Vaccinium macrocarpon Ait.) vines was obtained using the wiper applicator and glyphosate (22, 69). The wiper applicator can dispense more herbicide than the ropewick applicator (72) and it can be adapted to treat weeds growing near the soil surface (17).

The roller applicator was first reported by Wyse and Habstritt (76). They obtained excellent control of quackgrass (Agropyron repens (L.) Beauv.) and reed canarygrass (Phalaris arundinacea L.) using 6, 18 and 36 g/L glyphosate solutions in Kentucky bluegrass (Poa pratensis L.) seed production fields. Selleck et al. (58) found that a 36 g/L glyphosate solution applied with a roller applicator was very effective in controlling many weeds that grew taller than potatoes, boxleaf holly (Ilex crenata convexa Makino) or strawberries (Fragaria virginiana Duchesne). The roller applicators, like the wiper applicators, convey more herbicide than the ropewick applicators, however dripping of the herbicide onto non-target plants is a problem (72). Also insufficient wetting of the absorbant material on the roller can be a problem (39).

The recirculating sprayer was designed for selective application of herbicides in row crops to weeds growing above the crop canopy. The use of 12 to 18 g/L solutions of 2,4-D ((2,4-dichlorophenoxy)acetic acid) in the recirculating sprayer provided excellent control of pigweed (*Amaranthus* sp.), cocklebur and sesbania (*Sesbania* sp.), while johnsongrass was effectively controlled with MSMA (monosodium methanearsonate) (43). Glyphosate applied in 1.5 to 24 g/L solutions gave good to excellent control of johnsongrass in soybeans (44). Seventy to 80% of the herbicide solution was recovered for reuse (15, 44). Boyles et al. (12) effectively controlled johnsongrass in cotton, soybeans and peanuts (*Arachis hypogaea* L.), however they noted no significant differences in yields between the various treatments. Similar results were reported by Carlson (15). One reason for these results was that at the time of application, weed-crop competition had already occurred. Hence, no increase in yield was noted even if weed control was good. Crop injury occurred using the recirculating sprayer (43, 44) which was probably due to splashing of the herbicide from the weeds onto the crop and the drift of fine spray particles (72).

Another low volume application method is called controlled drop application. Drops of uniform diameter are produced by a rotary atomizer (spinning discs) (18). Experiments were conducted applying a large number of herbicides with controlled drop applicators at 5 to 60 L/ha and conventional application at 165 to 225 L/ha. In most cases, a volume range was determined (approximately 20 to 60 L/ha) in which weed control comparable to that obtained with the conventional application method was obtained with controlled drop application (3, 4, 5, 16, 19, 33, 40, 45, 50, 64, 73, 74). Experiments using glyphosate (18, 22, 32) established superior results with the controlled drop applicators as compared to conventional spraying. Caseley et al. (16) stated that controlled drop application resulted in greater retention of the herbicide on the foliage which led to better weed control. Cussans and Taylor (19) indicated that many factors may affect the performance of controlled drop application. Some are drop size, formulation, herbicide dose, type of herbicide, size and form of crop and weeds, environment and the interactions of these factors.

Besides acceptable weed control, several other advantages arise with controlled drop application. Logistics are improved (hence shorter spraying time), access to wet soils is made possible by reduced sprayer weight, the danger of drift is reduced (4, 18, 19, 40, 63, 74), and in the case of glyphosate, herbicide activity is enhanced by decreasing the spray volume. However, there are also some disadvantages. The spray pattern is very difficult to see because so little spray solution is being applied, therefore overlap or skipping may be a problem. Also, this method is basically non-selective, hence controlled drop applicators are restricted to selective herbicides in the crop, or carefully directing the spray solution to the base of tree crops.

The McBryde Sugar Co. developed the 'brush' applicator for selectively applying glyphosate to dallisgrass (Paspalum dilatatum Poir.) growing in sugarcane (Saccharum officinarum L.). The applicator consisted of 12-610 mm x 0.88 mm micropore tubes (used for drip irrigation) that were imbedded in a main tube that came from the reservoir. The micropore tubes were wrapped along a 0.3 m aluminum boom. The system was gravity fed. An 18 g/L glyphosate solution plus 0.25% v/v wetting agent plus 0.25% v/v polyethylene oxide polymer (thickening agent) was used. Excellent weed control was obtained with no injury to the crop. Brush spraying replaced 98% of the knapsack spraying shortly after this method was developed (67).

Another method utilizes a knapsack sprayer, with a nozzle that sprays a fine solid stream of herbicide solution under low pressure (0.70 kg/cm^2). The diameter of the hole in the nozzle is approximately 0.36 mm. This apparatus has been named the 'Magicwand'. The herbicide solution can be selectively applied to target plants in and around the field. The Magicwand has been useful in selectively controlling weeds in sugarcane with an 18 g/L glyphosate solution and spray volumes of approximately 9.4 L/ha.[1]

Effect of Diluent Volume and Water Quality on Glyphosate Activity

Upchurch et al. (66) found that glyphosate activity on quackgrass was greater when applied in diluent volume of 94 L/ha than at 846 L/ha. Others have also reported increased glyphosate activity with decreasing spray volume (10, 37, 51, 52, 54, 55, 56, 57, 62, 71).

Water containing divalent or trivalent cations such as calcium, magnesium, iron, zinc and aluminum antagonize glyphosate activity (51, 54, 55, 56, 62). Glyphosate inhibition by cations may have been related to the charge on the ion, but factors other than valence were involved (51, 62). The increase in diluent volume increased the total amount of cations, hence the herbicidal activity of glyphosate was reduced. Evidence for this was shown as distilled or deionized water (free of salts) gave significantly better weed control than tap water at higher diluent volumes (56, 57, 62). However, even with distilled water, the higher diluent volumes resulted in reduced glyphosate activity (55, 56, 62).

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[1] Personal communication from Shigeo Uyeda, McBryde Sugar Company.

Riemer (52) reported that addition of surfactant to MON 2139 restored glyphosate activity on phragmites (*Phragmites communis* Trin.) at the high volume rate. The decreased control at the high spray volume was probably the result of dilution of the surfactant, therefore the additional surfactant restored activity to that of the low spray volume. Sandberg et al. (55) later reported that additional surfactant also increased glyphosate phytotoxicity on tall morningglory (*Ipomoea purpurea* (L.) Roth.), but it did not remove the loss of activity due to the increased diluent volume. Jordan (37) reported similar results with bermudagrass (*Cynodon dactylon* (L.) Pers.).

A 1.8 g/L glyphosate solution applied to bermudagrass (*Cynodon dactylon* (L.) Pers.) at 373 L/ha (671.4 g/ha glyphosate) was less effective than 3.6 and 5.4 g/L glyphosate solutions applied at 94 L/ha (338.4 and 507.6 g/ha glyphosate) (28). Thus the low diluent volume performed better than the high diluent volume even though the total amount of glyphosate applied by the low diluent volume was less.

Rogers and Worthington (53) reported no change in glyphosate activity on annual weed species and johnsongrass between diluent volumes of 187 and 374 L/ha. Jagchitz (35) found that changing the diluent volume from 804 to 3255 L/ha did not alter herbicidal activity on bentgrass (*Agrostis* sp.), crabgrass (*Digitaria* sp.), Kentucky bluegrass (*Poa* *pratensis* L.), perennial ryegrass (*Lolium perenne* L.), red fescue (*Festuca rubra* L.), tall fescue (*Festuca arundinacea* Schreb.), and white clover (*Trifolium repens* L.). The glyphosate rates used were 1.12 to 2.24 kg/ha. However, it was noted that weed control seldom reached 100%.

Poor water quality and high spray volumes resulted in decreased glyphosate activity, but it was also reported that distilled or deionized water at high diluent volume reduced glyphosate activity. Jordan (37) indicated that drop size, herbicide concentration in the drop and drop number were other factors that might be responsible for the variable results obtained with glyphosate.

Effect of Drop Size, Drop Concentration and Drop Number on Herbicide Phytotoxicity

Studies of drop characteristics have produced varied results, but many authors have shown that decreasing the drop size increases herbicide phytotoxicity (14, 24, 25, 34, 41, 42, 68). However, drop size is not an independent factor (48). For example, given a fixed volume and herbicide rate, a decrease in drop size increases the number of drops per given area (42, 68) and herbicide coverage is better. High, localized concentrations (large drops) of 2,4-D, 2,4,5-T ((2,4,5-trichlorophenoxy)acetic acid) and CIPC (isopropyl *m*-chloro-carbanilate) injured or killed cells below those areas, therefore reducing the rate of translocation from that area (25, 41). Some have found that there was no effect of drop size on herbicide activity. Buerhing et al. (14) indicated that activities of MSMA and amitrole (3-amino-1,2,4-triazole) were not affected by drop size. Mullison (47) also reported that drop size did not affect 2,4-D activity if the total amount of 2,4-D applied was the same. However, he used drop sizes of 2 and 6 uL which are much larger than drops with diameters of 200 and 300 um. Results might have differed if smaller droplets were used. Behrens (9) found that drop size and spray volume had little influence on herbicide activity, but that they are indirectly involved because drop spacing is a function of drop size and spray volume. He also indicated that the larger droplets applied in higher volumes were slightly more effective, possibly due to the longer period of moist contact which increased herbicide absorption.

Finally, it has also been reported that larger drops were more effective than smaller drops (29, 59). Smith (59) found that 2,4-D in larger drops (250 to 561 um diam.) were more effective than small drops (30 um). However, the plants were treated in a chamber and it was noted that the small droplets remained suspended in the air for a time. It was also pointed out that spraying at high pressure (2.81 kg/cm^2) to produce the small drops was not favorable for leaf interception. The leaf angle was probably more acute and a higher percentage of drops may have collected on the walls of the chamber due to turbulence effects (25). Fisher et al. (29) reported that 500 um drops were equally or slightly more effective than 100 um drops. No explanation was given, but it is possible that drift may have been a probable cause for the decreased herbicide activity, as drops of 100 um or less constitute the major source of drift potential (30).

Ambach and Ashford (1) recently reported that one drop of glyphosate solution at 2 x 10^{-3}M with 0.5% v/v surfactant was significantly more effective than an equivalent amount of herbicide and adjuvant in a dilute concentration applied in larger drop number. But when the surfactant concentration in each drop was held constant at 0.5%, there was no significant difference between drop number and drop concentration. This suggests some interaction between spray volume, herbicide concentration and surfactant.

Thus, the nature of the effect of a low volume-high concentrate spray solution on glyphosate activity is not clear. Determining the basis for the enhanced activity would appear to have considerable practical economic implications.

CHAPTER III

LOW VOLUME APPLICATION METHODS OF GLYPHOSATE

Application of glyphosate (*N*-(phosphonomethyl)glycine) in recirculating sprayers, roller applicators and ropewick applicators have been rapidly accepted by farmers. For example, 2 years since the development of the ropewick applicator by Dale (20), 4 to 6 million hectares have been treated using this method (72). Some advantages with the methods mentioned above are that selectivity can be obtained (by placement), diluent volume is reduced and drift is minimal or none at all.

Glyphosate activity was increased when the diluent volume was reduced (37, 66), hence it would be advantageous to apply glyphosate by these methods.

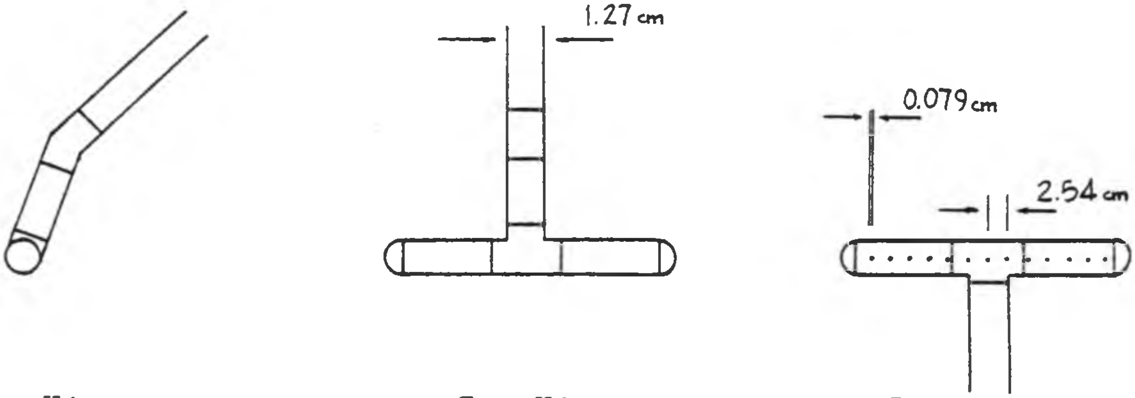
In this study, low volume applicators were used to apply glyphosate. Purple nutsedge (*Cyperus rotundus* L.), white thunbergia (*Thunbergia fragrans* Roxb.), guineagrass (*Panicum maximum* Jacq.) and guava (*Psidium guajava* L.) represent plants with different growth habits.

MATERIALS AND METHODS

Description of the low volume applicators used:

1. *Wiper applicator*: The main frame is constructed from 1.27 cm diamter PVC pipe (Fig 1.). On the bottom of the crosspiece, 0.079 cm diam. holes were drilled 2.54 cm apart. Absorbant cotton material was wrapped around the

crosspiece and secured with cotton twine. The cotton twine was wrapped very close together so the entire surface of the wiper crosspiece was covered with cotton twine. The herbicide solution was poured into the shaft, and when the absorbant material was thoroughly wet, the herbicide solution was wiped onto the target plants. Glyphosate concentrations used were 36 and 90 g a.e./L (10 and 25% v/v, respectively).



Side View Top View Bottom View

Figure 1.--Diagram of the wiper applicator.

2. <u>Brush applicator</u>: The frame from the wiper applicator was used (Fig. 2). Twelve-5 uL micropipettes were inserted into the plastic tubing at 2.54 cm intervals. The system was gravity fed and the flow rate could be regulated by a clamp. The herbicide solution was dripped onto the target material. The flow rate was approximately 1.67 to 2.50 ml/sec and the walking speed was about 0.61 m/sec. Glyphosate concentration used were 18 and 36 g a.e./L (5 and 10% v/v, respectively).

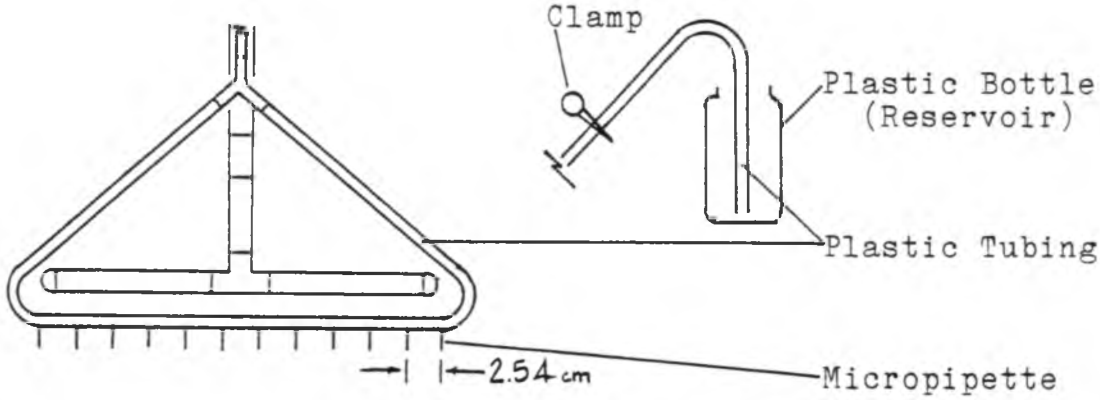


Figure 2.--Diagram of the brush applicator.

3. Magicwand: A knapsack sprayer with a non-atomizing nozzle that has a 0.36 mm diameter hole. A fine solid stream of herbicide solution was directed at the target plants. The spray pressure was approximately 0.70 kg/cm^2 and the discharge rate was about 0.9 ml/sec. Walking speed was approximately 0.61 m/sec. Glyphosate concentrations used were 18 and 36 g a.e./L.

Conventional application method: This method served as a standard with which to compare the various low volume applicators. In pot studies, plants were sprayed on a track-type sprayer which was calibrated to deliver 374 L/ha at 2.11 kg/cm^2 using a conventional 9506E nozzle. Glyphosate rates used were 3.6 and 7.2 g/L (1.35 and 2.70 kg a.e./ha, respectively).

In the nutsedge field study the plants were sprayed using a 9506E nozzle at 2.11 kg/cm^2. Walking speed was approximately 1 m/sec to deliver 374 L/ha. The same rates were used as in the pot studies.

Response of thunbergia to various application methods of glyphosate: Two seedlings per 15.2 cm diam. pot were allowed to become well established in full sunlight. They were allowed to grow for about 4 months and the stems were occaisionally trimmed back to approximately 20.3 cm in length. At the time of treatment, plants were uniform in size and were flowering. The experimental design was a completely randomized design with 6 replications.

Since thunbergia has a prostrate growth habit, and much of the foliage was draped over the edge of the pot. The pot was placed in a frame constructed of a flat piece of plywood approximately 0.61 m in diam. with a 15.2 cm diam. hole cut out of the center. The plywood was raised 17.8 cm to match the height of the pot. The frame was used to simulate the plant growing on the ground and it also allowed a normal leaf area exposure to the applicators.

Two passes over the thunbergia plants were made with the wiper applicator (not overlapping) to obtain a 0.61 m swath. It was noted that approximately 30% of the foliage was covered with the glyphosate solution. The abaxial surface of some leaves also received glyphosate solution.

The brush applicator was used in the same manner as the wiper applicator, with approximately the same discharge rates and walking speeds previously described. Coverage was not uniform and some leaves did not receive any glyphosate solution. Approximately 10% of the foliage was covered.

The Magicwand applicator was used in the same manner as the purple nutsedge experiment. Like the drip applicator spray coverage was not uniform and some leaves were not sprayed. It was noted that less than 10%, but more than 5% of the foliage was covered.

Visual ratings of thunbergia injury were made 1 and 2 weeks after treatment. Shoot fresh weights were recorded 3 weeks after treatment and regrowth shoot fresh weights were recorded 8 weeks after treatment.

Response of purple nutsdege to various application methods of glyphosate: A previously established field of purple nutsedge at the Waimanalo Research Station, Hawaii Institute of Tropical Agriculture and Human Resources (HITAHR), Oahu was used. At the time of treatment, nutsedge plants were 13 to 18 cm in height and were flowering. The plots were 0.91 m x 7.58 m in a randomized complete block design with 4 replications.

The wiper applicator was pulled through the nutsedge plot close to the soil surface (2.5 to 5.1 cm) without touching the soil. Three adjacent 0.3 m passes were made to cover the 0.91 m wide plot. The applicator was pulled over the plants only once. A visual estimate of the percent of the foliage covered by the herbicide solution was recorded at the time of treatment. Approximately 20% of the foliage was covered with glyphosate solution by this method. Some of the solution was wiped onto the underside of the leaves.

Visual ratings of nutsedge injury were made 2 and 4 weeks after treatment. Counts of live nutsedge plants for 1 to 3-0.09 sq. m. samples (depending on weed density) were recorded 4 weeks after treatment. Seven weeks after treatment, 25 tubers per plot were harvested (to a depth of 15 to 20 cm) at random and placed in 9.0 cm diam. Petri dishes on Whatman No. 1 filter paper. The tubers were initially watered with 5 ml of 100 ppmw benzyl adenine (BA) solution per Petri dish. Subsequent watering with the BA solution was done at weekly intervals. Tap water was used to keep the tuber moist between weekly waterings of the BA solution. Petri dishes were kept in the laboratory at 25 $\pm$ 2° C. Percent tuber germination was recorded 8 and 11 weeks after treatment.

Response of guava to various application methods of glyphosate: Semi-hardwood guava cuttings (cv. 'Beaumont') approximately 7.6 cm long, were rooted and transplanted in 15.2 cm diam. pots (one cutting per pot). Plants were allowed to become well established (25 weeks) in full sunlight, during which time floral buds were regularly removed to force all the plants to remain in the vegetative state. The plants were approximately 36 to 46 cm in height at the time of treatment. The experimental design was a randomized complete block with 6 replications.

The wiper applicator was pulled through the guava plants only once. Approximately 20% of the foliage was covered with herbicide solution. Most of it was on the abaxial surface of the leaves.

The brush applicator was also used with only one pass over the plants with about 10% of the foliage being covered, mostly on the adaxial leaf surface. The Magicwand obtained similar coverage.

Visual ratings of guava injury were made 3 weeks after treatment. Plant heights and shoot fresh weights were recorded 4 weeks after treatment. Finally, regrowth shoot fresh weights were recorded 10 weeks after treatment.

Response of guineagrass to various application methods of glyphosate: Three guineagrass crown pieces were planted per 15.2 cm diam. pot. They were allowed to grow for 5 weeks in full sunlight. Plants were approximately 61 to 76 cm in height at the time of treatment. The experimental design was a randomized complete block with 6 replications.

Glyphosate was applied to the guineagrass with only one pass of the wiper applicator. Approximately 20% of the foliage was covered with the glyphosate solution, with some solution coating the abaxial surface of some leaves.

The drip applicator was also used with only one pass over the guineagrass. Approximately 10% of the foliage was covered. Similar coverage was obtained with the Magicwand applicator.

Visual ratings of guineagrass injury were made 2 weeks after treatment. Shoot fresh weights were recorded 3 weeks after treatment and regrowth shoot fresh weights were recorded 7 weeks after treatment.

RESULTS AND DISCUSSION

Response of thunbergia to glyphosate applied with various applicators: Symptoms of glyphosate damage to thunbergia were leaf chlorosis followed by leaf drop and finally necrosis of the remaining stem and leaf tissues. Two weeks after treatment, visual ratings showed that thunbergia was controlled by glyphosate applied with the brush applicator (5 and 10% v/v), the wiper applicator (10 and 25% v/v) and the conventional application method (2% v/v) (Table 1). Three weeks after treatment, shoot fresh weight was reduced by all glyphosate applications. The shoot fresh weight in the conventional spray application using 1% v/v glyphosate and the Magicwand using 5% v/v glyphosate was greater than the other application methods, indicating that these treatments were less effective. At 8 weeks, only the Magicwand using 5% v/v glyphosate had significant regrowth . However, it should be noted that the conventional spray treatment using glyphosate at 1% v/v had some regrowth, although it was not different from the other treatments that had no shoot regrowth.

These results showed that the treatments used were effective in completely controlling thunbergia, except the Magicwand with 5% v/v and the conventional method with 1% v/v. The manner in which glyphosate was applied with the

Table 1.--Response of thunbergia to glyphosate applied in various applicators.[a]

Treatment	Visual Ratings (% of the Untreated Control) 1 wk	Visual Ratings (% of the Untreated Control) 2 wk	Shoot Fresh Weight (g) 3 wk	Regrowth Shoot Fresh Weight (g) 8 wk
Untreated Control	100a	100a	59.2a	17.9a
Conventional 1% v/v @ 374 L/ha[b]	99a	97a	42.5b	0.2c
Conventional 2% v/v @ 374 L/ha[c]	36c	2c	6.3cd	0.0c
Magicwand 5% v/v	100a	100a	49.9b	5.4b
Magicwand 10% v/v	80b	46b	15.9c	0.0c
Brush Applicator 5% v/v	37c	0c	7.6cd	0.0c
Brush Applicator 10% v/v	31cd	1c	6.6cd	0.0c
Wiper Applicator 10% v/v	23cd	3c	9.1cd	0.0c
Wiper Applicator 25% v/v	6cd	0c	4.6d	0.0c

[a]Within columns, values followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Equivalent to 1.35 kg a.e./ha.

[c]Equivalent to 2.70 kg a.e./ha.

Magicwand resulted in poor coverage of the foliage, which may explain the poor control obtained at the 5% v/v rate. The Magicwand probably applied the least amount of glyphosate solution to the plants. However, increasing the glyphosate concentrations of the Magicwand and conventional methods to 10% and 2% v/v respectively, increased glyphosate activity to the level of the other methods. If better coverage was obtained with the Magicwand at 5% v/v, control of thunbergia could have equalled the control obtained by the other methods.

Response of purple nutsedge to glyphosate applied with various applicators: Two weeks after treatment, the most active treatments were the wiper applicator with 25% v/v glyphosate and the conventional application method with 2% v/v glyphosate (Table 2). The initial symptom was chlorosis, followed by necrosis of the leaf tissue. At 4 weeks, the same treatments provided the best control, as shown by visual ratings and counts of live plants. The Magicwand treatments with 5 and 10% v/v glyphosate and the brush applicator treatment with 5% v/v glyphosate did not perform well, as indicated by the counts of live plants. This was probably due to poor herbicide coverage. With the type of deposition pattern that was delivered by the Magicwand and the brush applicator, coupled with a relatively dense weed stand, good coverage was a problem with these applicators. However, this was not readily

Table 2.--Response of purple nutsedge to glyphosate applied in various applicators.[a]

Treatment	Visual Ratings (% of the Untreated Control) 2 wk	4 wk	Counts of Live Plants per 0.09 sq. m. 4 wk	Germination of Tubers (%) 8 wk	11 wk
Untreated Control	100a	100a	33.3a	74.1a	83.5a
Conventional 1% v/v @ 374 L/ha[b]	84bc	50cd	17.6bc	0.5b	7.8bc
Conventional 2% v/v @ 374 L/ha[c]	45e	1f	2.8d	0.3b	0.5c
Magicwand 5% v/v	93b	89b	29.9ab	3.6b	22.0b
Magicwand 10% v/v	84bc	56c	20.2abc	0.0b	4.2c
Brush Applicator 5% v/v	89bc	85b	20.8abc	2.6b	22.2b
Brush Applicator 10% v/v	65d	28cde	10.7c	0.0b	1.9c
Wiper Applicator 10% v/v	77cd	24de	14.7c	1.5b	9.3bc
Wiper Applicator 25% v/v	46e	6ef	2.3d	0.0b	0.5c

[a]Within columns, values followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Equivalent to 1.35 kg a.e./ha.

[c]Equivalent to 2.70 kg a.e./ha.

indicated by the tuber germination test at 8 weeks. All treatments except the untreated control suppressed tuber sprouting. However, at 11 weeks some tubers were still alive, especially those in treatments receiving lower glyphosate concentrations.

These results indicated that dormancy may have been induced by glyphosate in the nutsedge tubers. It has been shown that glyphosate application to yellow nutsedge (*Cyperus esculentus* L.) plants increased the number of dormant tubers (2). Also, field conditions were dry, and it may be possible that translocation of glyphosate was limited as the plants may have been water stressed even though the plants did not appear to be stressed.

Response of guava to glyphosate applied with various applicators: Chlorosis and some anthocyanescence occured on the young foliage in most treatments. Treatments with the higher rates of glyphosate (wiper applicator with 10 and 25% v/v glyphosate, brush applicator with 10% v/v glyphosate and the Magicwand with 10% v/v glyphosate) also had tip burn and leaf drop, and in some cases the growing tips were killed. Plant height and shoot fresh weight data both showed that the wiper applicator treatments with 10 and 25% v/v glyphosate were the most effective in controlling guava (Table 3). The wiper applicator with 10 and 25% v/v glyphosate and the Magicwand with 10% v/v glyphosate were the most effective in controlling guava regrowth. The wiper

Table 3.--Response of guava to glyphosate applied in various applicators.[a]

Treatment	Visual Ratings (% of the Untreated Control) 3 wk	Plant Height (cm) 4 wk	Shoot Fresh Weight (g) 4 wk	Regrowth Shoot Fresh Weight (g) 10 wk
Untreated Control	100a	60.3ab	80.6a	11.6a
Conventional 1% v/v @ 374 L/ha[b]	74b	57.8abc	81.0a	7.5b
Conventional 2% v/v @ 374 L/ha[c]	71bc	55.2abcd	69.3ab	6.0b
Magicwand 5% v/v	70bc	53.5bcd	67.3ab	6.8b
Magicwand 10% v/v	60de	50.3d	59.0b	2.0c
Brush Applicator 5% v/v	74b	61.3a	67.2ab	6.5b
Brush Applicator 10% v/v	65cd	51.0cd	61.8b	5.3b
Wiper Applicator 10% v/v	55ef	43.0e	39.4c	0.6c
Wiper Applicator 25% v/v	50ef	40.2e	36.0c	1.2c

[a]Within columns, values followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Equivalent to 1.35 kg a.e./ha.

[c]Equivalent to 2.70 kg a.e./ha.

applicator may have had an advantage over the other application methods in that some (or most) of the herbicide solution was applied to the abaxial surface of the leaves. Less cuticle and more stomates might have facilitated better herbicide penetration. However, it should be noted that none of the guava plants were completely dead, as indicated by the regrowth data. These results show that guava is tolerant to glyphosate. Regrowth that occurred in treatments with high activity (wiper applicator with 10 and 25% v/v glyphosate) had many, very small adventitious buds formed at the nodes. Baur et al. (8) obtained a similar response on sorghum (Sorghum bicolor (L.) Moench 'Tophand'). He reported that the sorghum seedlings showed a swollen basal zone with a proliferation of auxiliary buds breaking from that zone. A later study by Baur (7) suggested that this response resulted from the alteration of the auxin-cytokinin balance, as glyphosate possibly affected auxin transport. Those treatments with less activity appeared to have less adventitious buds formed and some of those buds had formed larger shoots.

On guava, these low volume applicators were just as effective or more so than the conventional method, although the herbicidal activity was less than with the other weed species. Hence, if the Magicwand and the brush applicators were used in a manner that provided better coverage, then these application methods may have provided better control of guava than the conventional method.

Response of guineagrass to glyphosate applied with various applicators: At 2 weeks, most treatments had considerable herbicidal effects on guineagrass. Most of the plant material was dead (necrotic) or dying (chlorotic). Although the shoot fresh weight data indicated differences among treatments, regrowth data at 7 weeks showed that all methods were effective in controlling guineagrass (Table 4). These data indicate that guineagrass is extremely sensitive to glyphosate and that these low volume-high concentrate methods can effectively control this weed.

Table 4.--Response of guineagrass to glyphosate applied in various applicators.[a]

Treatment	Visual Ratings (% of the Untreated Control)	Shoot Fresh Weight (g)	Regrowth Shoot Fresh Weight (g)
	2 wk	3 wk	7 wk
Untreated Control	100a	136.5a	41.7a
Conventional 1% v/v @ 374 L/ha[b]	14b	51.7bc	0.0b
Conventional 2% v/v @ 374 L/ha[c]	2d	32.2d	0.0b
Magicwand 5% v/v	13bc	54.3b	0.0b
Magicwand 10% v/v	12bc	48.3bcd	0.0b
Brush Applicator 5% v/v	12bc	45.5bcd	0.0b
Brush Applicator 10% v/v	9bcd	44.3bcd	0.0b
Wiper Applicator 10% v/v	5cd	40.4bcd	0.0b
Wiper Applicator 25% v/v	9bc	35.4cd	0.0b

[a]Within columns, values followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Equivalent to 1.35 kg a.e./ha.

[c]Equivalent to 2.70 kg a.e./ha.

CHAPTER IV

EFFECT OF DILUENT VOLUME ON GLYPHOSATE ACTIVITY

Many investigations have shown that decreased spray volume and good water quality increased glyphosate activity (10, 37, 51, 52, 54, 55, 56, 57, 62, 66, 71).

The purpose of this study was to determine if lower diluent volumes increased glyphosate activity on important perennial weed species of Hawaii. A survey of the water quality on Oahu showed that the combined calcium and magnesium concentrations seldom exceeded 80 ppm, iron and aluminum concentrations were less than 0.02 ppm and total hardness seldom exceeded 250 ppm (11, 65). If the total hardness exceeded 250 ppm, most of the hardness was due to chloride, which does not affect glyphosate activity (62). Hence, the use of tap water on Oahu would not appear to pose a problem in reducing glyphosate activity. Glyphosate activity was evaluated on the same 4 weed species (purple nutsedge, thunbergia, guava and guineagrass) used in the low volume applicator study.

MATERIALS AND METHODS

In the pot studies, all plants were treated on a track-type laboratory sprayer with glyphosate rates of 0.0, 0.5, 1.0, 2.0 and 4.0 kg a.e./ha, and applied in 45, 90, 180 and 360 L/ha of tap water.

Response of purple nutsedge to various diluent volumes and glyphosate rates: An established purple nutsedge field at the Waimanalo Research Station, HITAHR, Oahu, was used. At the time of treatment the purple nutsedge plants were 13 to 18 cm in height and were flowering. The plots were 1.5 m x 7.6 m and the experimental design was a randomized complete block with 4 replications. The glyphosate rates were 0, 0.5, 1.0 and 2.0 kg a.e./ha. They were applied in diluent volumes of 90, 180 and 360 L/ha. Visual ratings were made 2 and 4 weeks after treatment. Counts of live purple nutsedge plants for 1 to 3-0.09 sq. m. samples (depending on weed density) were recorded 4 weeks after treatment. Seven weeks after treatment, 25 nutsedge tubers and basal bulbs were collected (to a depth of 15 to 20 cm) at random and placed in 9.0 cm diam. Petri dishes on Whatman No. 1 filter paper. The tubers were watered once weekly with 5.0 ml of 100 ppmw benzyl adenine (BA) solution. The tubers were kept moist with deionized water between weekly waterings with the BA solution. Percent tuber germination was recorded 8 and 11 weeks after treatment.

A pot study supplemented the experiment performed in the field. Five tubers were planted per 12.7 cm diam. pot. Plants were allowed to grow for 5 weeks in full sunlight before treatment. At the time of treatment, nutsedge plants were 12.7 to 17.8 cm in height and were flowering. The experimental design was a randomized complete block design with 6 replications.

Visual ratings made taken 2 and 3 weeks after treatment. Shoot fresh weights and number of tubers per pot were recorded 3 weeks after treatment. All tubers and basal bulbs were harvested from each pot and placed in 9.0 cm diam. Petri dishes on Whatman No. 1 filter paper. The tubers were watered weekly with 5.0 ml of 100 ppmw BA solution. They were kept moist with deionized water between weekly waterings with the BA solution. Percent tuber germination was recorded 11 weeks after treatment.

Response of thunbergia to various diluent volumes and glyphosate rates: Two thunbergia plants were allowed to become well established in 15.2 cm diam. pots in full sunlight. They were occasionally trimmed back to uniform size (20.3 cm). At the time of treatment the thunbergia was flowering. The experimental design was a randomized complete block with 6 replications.

The plants were placed in the same wooden frame as described in the low volume applicators chapter. The purpose of this was to simulate treatment of the plant as if it was on the ground.

Visual ratings were made 1 and 2 weeks after treatment. Shoot fresh weight was recorded 3 weeks after treatment and regrowth shoot fresh weight was recorded 8 weeks after treatment.

Response of guava to various diluent volumes and glyphosate rates: Semi-hardwood guava (cv. 'Beaumont') cuttings, approximately 7.6 cm long, were rooted and transplanted in 15.2 cm diam. pots (1 cutting per pot). Plants were allowed to become well established before treatment (25 weeks after transplanting), during which time the floral buds were removed to force all plants to remain in the vegetative state. At the time of treatment, the plants were approximately 38 to 51 cm in height. The experimental design was a randomized complete block with 6 replications.

Visual ratings made 3 weeks after treatment. Plant height and shoot fresh weight were recorded 4 weeks after treatment. Regrowth shoot fresh weight was recorded 10 weeks after treatment.

Response of guineagrass to various diluent volumes and glyphosate rates: Three single crown pieces were planted per 15.2 cm diam. pot. They were allowed to grow for 4 weeks in full sunlight before treatment. The plants were approximately 51 to 76 cm in height at the time of treatment. The experimental design was a randomized complete block with 6 replications.

Visual ratings were made 2 weeks after treatment. Shoot fresh weight was recorded 3 weeks after treatment and regrowth shoot fresh weight was recorded 6 weeks after treatment.

RESULTS AND DISCUSSION

Response of thunbergia to various diluent volumes and glyphosate rates: Glyphosate rates of 1, 2 and 4 kg a.e./ha were effective in controlling thunbergia at all diluent volumes tested, as indicated by visual ratings, shoot fresh weight and regrowth data (Table 5). However, at the 0.5 kg a.e./ha rate, thunbergia injury decreased as the diluent volume increased.

Regrowth data at the 0.5 kg a.e./ha rate also showed that increased diluent volume reduced glyphosate activity. However, at the 180 L/ha spray volume, there was no regrowth, although it was expected. One possible reason for this is that at the time the shoots were harvested (3 weeks after treatment), the growing point at the soil surface may have been accidentally damaged or removed, although special care was taken not to damage or remove these growing points. It is also possible that fungi or other plant pathogens may have infected and killed the plants as the shoots were cut near the medium surface. It should be noted that there is virtually no difference in shoot regrowth between diluent volumes at the 0.5 kg a.e./ha glyphosate rate, yet the visual ratings and shoot fresh weight data showed differences. A possible explanation for this may be that the removal of the top growth of the treated plants, may have depleted their food reserves to the point where they could not recover.

Table 5.--Response of thunbergia to various diluent volumes and glyphosate rates. Data are expressed as percentages of the untreated control.[a]

Treatment: Diluent Volume (L/ha)	Treatment: Glyphosate Rate (kg a.e./ha)	Visual Ratings (%) 1 wk[b]	Visual Ratings (%) 2 wk[b]	Shoot Fresh Weight (%) 3 wk[b]	Regrowth Shoot Fresh Weight (%) 8 wk[b]
45	0.5	12d	2c	6c	0b
90	0.5	27bc	13b	12c	14b
180	0.5	32b	21b	21b	0b
360	0.5	74a	74a	51a	84a
45	1.0	11d	0c	4c	0b
90	1.0	11d	0c	6c	0b
180	1.0	16cd	2c	7c	0b
360	1.0	19bcd	1c	9c	0b
45	2.0	11d	0c	6c	0b
90	2.0	10d	0c	6c	0b
180	2.0	11d	0c	6c	0b
360	2.0	11d	0c	5c	0b
45	4.0	10d	0c	5c	0b
90	4.0	10d	0c	5c	0b
180	4.0	10d	0c	5c	0b
360	4.0	10d	0c	6c	0b

[a]Within columns, values followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Significant diluent volume x glyphosate rate interaction.

Comparing the results of this experiment (Table 5) with those of the conventional application method in the low volume applicator study (Table 1), showed that there was greater glyphosate activity on shoot fresh weight in this experiment. There was no discernable difference in regrowth. A possible explanation could be that the plants in this experiment were treated in spring (March 25, 1981), as opposed to the low volume applicator study plants which were treated in late summer (August 20, 1981). Environmental conditions and growth rate of the plants may have been a factor for increased susceptibility of thunbergia to glyphosate. Thunbergia growth rate may have been slower in late summer if conditions were dry, as thunbergia prefers moist conditions. Hence, absorption and translocation of glyphosate may have been reduced. It is also possible that a thicker cuticle may have developed on the plants growing in late summer, thus hindering glyphosate absorption even more.

Visual ratings and shoot fresh weight data showed significant diluent volume x glyphosate rate interactions.

Lowering the glyphosate rate to 0.25 kg a.e./ha might have resulted in a more clear cut trend of decreased glyphosate activity at the higher diluent volumes, as the 1.0 kg a.e./ha rate was too high.

Response of purple nutsedge to various diluent volumes and glyphosate rates: The results obtained in the field did not show any diluent volume x glyphosate rate interaction for any of the measurements taken, except visual ratings at 4 weeks (Table 6). Glyphosate action was slow, at 2 weeks there was only 42% control in the most extreme case. Field conditions were dry. This environmental condition might have been responsible for the slow herbicidal action of glyphosate. Visual ratings at 4 weeks showed that at the 1 kg a.e./ha rate, glyphosate activity decreased as the diluent volume increased. This trend was also shown at the 0.5 kg a.e./ha rate in counts of live plants and tuber germination at 8 weeks. Many tubers germinated from 8 weeks to 11 weeks after treatment, especially in the 0.5 and 1.0 kg a.e./ha glyphosate rates. It appeared that dormancy of the tubers was induced by glyphosate as in the low volume applicator study.

The pot study showed no diluent volume x glyphosate rate interaction for any of the parameters measured (Table 7). At 2 weeks, much of the plant material was dead or nearly dead, even at the 0.5 kg a.e./ha rate. Purple nutsedge was considerably more susceptible in this study (Table 7), as compared to the field study (Table 6). This could have been due to the favorable environmental conditions in which the nutsedge plants were growing. These conditions could have facilitated more rapid glyphosate absorption and translocation than plants growing in the field. Whitwell and Santelmann (75) stated that dry soil

Table 6.--Response of purple nutsedge to various diluent volumes and glyphosate rates; in the field. Data are expressed as percentages of the untreated control.[a]

Treatment: Diluent Volume (L/ha)	Treatment: Glyphosate Rate (kg a.e./ha)	Visual Ratings (%) 2 wk	Visual Ratings (%) 4 wk[b]	Counts of Live Plants per 0.09 sq. m. (%) 4 wk	Germination of Tubers (%) 8 wk	Germination of Tubers (%) 11 wk
90	0.5	91ab	94ab	70b	9bc	63a
180	0.5	93ab	93ab	76ab	14ab	49a
360	0.5	95ab	95a	89a	25a	54a
90	1.0	83c	63c	65b	6bc	18bc
180	1.0	88bc	84b	66b	8bc	27b
360	1.0	90ab	86b	81ab	5bc	16bc
90	2.0	58e	13d	30c	1bc	3c
180	2.0	64de	18d	27c	0c	5bc
360	2.0	68d	22d	39c	1bc	3c

[a]Within columns, values followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Significant diluent volume x glyphosate rate interaction.

Table 7.--Response of purple nutsedge to various diluent volumes and glyphosate rates; in pots. Data are expressed as percentages of the untreated control.[a]

Treatment: Diluent Volume (L/ha)	Treatment: Glyphosate Rate (kg a.e./ha)	Visual Ratings (%) 1 wk	Visual Ratings (%) 2 wk	Shoot Fresh Weight (%) 3 wk	Number of Tubers per Pot (%) 3 wk	Germination of Tubers (%) 11 wk
45	0.5	31a	12ab	34abc	36a	1b
90	0.5	33a	13a	31abcd	44a	2b
180	0.5	31a	12ab	37a	42a	3ab
360	0.5	33a	12ab	34ab	43a	8a
45	1.0	20ab	7abc	28bcdef	42a	1b
90	1.0	14bc	4cd	27cdef	43a	0b
180	1.0	13bc	5bc	29bcde	42a	0b
360	1.0	12bc	1de	24def	40a	0b
45	2.0	6c	1e	24def	41a	0b
90	2.0	5c	1e	23ef	38a	0b
180	2.0	5c	0e	22ef	40a	0b
360	2.0	0d	0e	23ef	43a	0b
45	4.0	0d	0e	22ef	43a	0b
90	4.0	0d	0e	23ef	41a	0b
180	4.0	1d	0e	21f	35a	0b
360	4.0	1d	0e	23ef	39a	0b

[a]Within columns, volues followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

conditions possibly reduced translocation of glyphosate in bermudagrass, and that bermudagrass should be actively growing for effective control with glyphosate. Doll and Piedrahita (23) said that absorption and translocation of glyphosate in purple nutsedge are reduced under hot, dry conditions. This could be a reason for reduced glyphosate activity showm in the field studies.

Tuber germination at 11 weeks, at the 0.5 kg a.e./ha rate showed that the low diluent volume was slightly more active than the high diluent volume. Because of the degree of susceptibility of purple nutsedge to glyphosate in this experiment, it was difficult to obtain useful interpretations on the modification of glyphosate activity by diluent volume. Due to the high glyphosate activity in this pot experiment, tuber dormancy did not occur as it did in the field study.

Response of guava to various diluent volumes and glyphosate rates: Symptoms of glyphosate injury occurred slowly. At 3 weeks, only 45% control was estimated visually at the 4.0 kg a.e./ha glyphosate rate (Table 8). Visual ratings was the only parameter that showed a diluent volume x glyphosate rate interaction. Visual ratings at 3 weeks showed that at the 0.5 kg a.e./ha rate, spraying a volume of 45 L/ha performed better than spraying at 180 and 360 L/ha, and that spraying at 90 L/ha was better than spraying at 360 L/ha. Four weeks after treatment, plant height showed a

Table 8.--Response of guava to various diluent volumes and glyphosate rates. Data are expressed as percentages of the untreated control.[a]

Treatment Diluent Volume (L/ha)	Glyphosate Rate (kg a.e./ha)	Visual Ratings (%) 3 wk[b]	Plant Height (%) 4 wk	Shoot Fresh Weight (%) 4 wk	Regrowth Shoot Fresh Weight (%) 10 wk
45	0.5	74cde	83abc	81abc	80ab
90	0.5	82bc	88ab	75bc	59bcde
180	0.5	85b	89ab	86ab	74abc
360	0.5	94a	91a	97a	92a
45	1.0	69def	68def	67bcde	68abcd
90	1.0	77bcd	80abc	59cdef	30efgh
180	1.0	72cde	79bc	83ab	59bcde
360	1.0	75bcde	89ab	79abc	83ab
45	2.0	63efg	65efg	66bcde	40defg
90	2.0	60fg	62fg	52def	30efgh
180	2.0	67defg	75cde	73bcd	37defgh
360	2.0	69def	77cd	76abc	47cdef
45	4.0	58fg	54g	50ef	18fgh
90	4.0	60fg	60fg	59cdef	11gh
180	4.0	55g	61fg	50ef	5h
360	4.0	58fg	56g	42f	7gh

[a]Within columns, values followed by the same letter are not significnatly different at the 5% level according to Duncan's multiple range test.

[b]Significant diluent volume x glyphosate rate interaction.

similar trend at the 1.0 and 2.0 kg a.e./ha rates. At the 1.0 kg a.e./ha rate, the 45 L/ha spray volume had better activity than the 360 L/ha spray volume and at the 2.0 kg a.e./ha rate, the 90 L/ha spray volume had better activity than the 360 L/ha spray volume. Shoot fresh weight data also showed similar results.

Regrowth data at the 0.5 kg a.e./ha rate showed that the 90 L/ha spray volume controlled regrowth better than 360 L/ha.

In general, the trend of decreased glyphosate activity with increased volumes was expressed by guava. It should be noted that glyphosate did not kill the guava plants, as was evidenced by the regrowth data. This gives further evidence that guava is tolerant to glyphosate.

One anomaly occurred in the regrowth data at the 1.0 kg a.e./ha rate. Although the 90 L/ha spray volume performed better than the 360 L/ha spray volume, it also performed better than the 45 L/ha spray volume. This anomaly is difficult to explain as visual ratings indicated no volume differences and plant height showed that the lower diluent volume was more active. One possibility is that regrowth data may not be the most reliable parameter to measure for guava. Another possibility is that a threshold level was reached where decreasing the diluent volume did not increase glyphosate activity. Shoot fresh weight and regrowth data at the 0.5, 1.0 and 2.0 kg/ha rates, showed that the 45 L/ha spray volume seemed to be less active (though not different) than the 90 L/ha spray volume. This could be related to spray interception. Smith (59) reported that applications of 3.1 kg/ha 2,4-D to kidney beans (Phaseolus vulgaris) using 250 and 125 ppm concentrations (123 and 246 L/ha, respectively), were more active in reducing fresh weight of new leaves than lower or higher diluent volumes. He indicated that a higher percentage of the spray was retained at these diluent volumes than lower or higher volumes. This may be an indication of an optimum spray volume.

Shoot regrowth on these plants was similar to that obtained in the low volume study, proliferation of adventitious buds at the nodes.

Response of guineagrass to various diluent volumes and glyphosate rates: Visual ratings at 2 weeks showed reduced glyphosate activity with increased spray volume at the 0.5, 2.0 and 4.0 kg a.e./ha glyphosate rates. In general, the 45 and 90 L/ha spray volumes performed better than the 180 and 360 L/ha spray volumes (Table 9).

Shoot fresh weight data also showed a similar trend at the 0.5 and 2.0 kg a.e./ha rates. At the 0.5 kg a.e./ha rates, the 45 L/ha spray volume performed better than 180 L/ha, and at the 2.0 kg a.e./ha rate, the 45 and 180 L/ha spray volumes reduced fresh weight more than the 360 L/ha spray volume.

Table 9.--Response of guineagrass to various diluent volumes and glyphosate rates. Data are expressed as percentages of the untreated control.[a]

Treatment: Diluent Volume (L/ha)	Treatment: Glyphosate Rate (kg a.e./ha)	Visual Ratings (%) 2 wk	Shoot Fresh Weight (%) 3 wk	Regrowth Shoot Fresh Weight (%) 6 wk[b]
45	0.5	65bcde	45bc	5b
90	0.5	85abc	49abc	19b
180	0.5	92ab	63a	69a
360	0.5	97a	53ab	67a
45	1.0	58cde	48abc	3b
90	1.0	76abc	49abc	53a
180	1.0	73abcd	41bcde	16b
360	1.0	89abc	48abc	46a
45	2.0	7gh	25f	0b
90	2.0	33efg	33cdef	0b
180	2.0	39def	27ef	1b
360	2.0	78abc	43bcd	14b
45	4.0	1h	18f	0b
90	4.0	18fgh	20f	0b
180	4.0	21fg	29def	0b
360	4.0	56cde	32cdef	0b

[a]Within columns, values followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Significant diluent volume x glyphosate rate interaction.

Regrowth of guineagrass showed a reduction of glyphosate activity at the higher diluent volumes. At the 0.5 kg a.e./ha rate, the 180 and 360 L/ha spray volumes were less effective than the 45 and 90 L/ha spray volumes. Regrowth did occur at the 180 and 360 L/ha spray volumes at the 2.0 kg a.e./ha rate, even though they were not different from the 45 and 90 L/ha spray volumes. The trend of decreased glyphosate activity with increased diluent volumes was clearly observed in this study.

The plants in this study appear to be more tolerant of glyphosate than the plants treated by the conventional application method in the low volume applicator study. The plants in the low volume applicator study may have been growing more rapidly than the plants in this study. Possible evidence of this was indicated by the size of the untreated plants, where the shoot fresh weight of the control plants in the low volume applicator study averaged 136.5 g/pot, and the shoot fresh weight of the control pots in this study averaged 67.9 g/pot. If plant growth in this study was less active at the time of treatment, glyphosate absorption and translocation may have been hindered, resulting in decreased control even at the higher rates.

One anomaly occurred at the 1.0 kg a.e./ha rate, where the 180 L/ha spray volume showed less regrowth than the 90 L/ha spray volume. This result was indeed confusing; harvesting shoot fresh weight initially may have damaged crown tissues of this treatment and also allowed fungi or other pathogens to infect and kill the plants.

CHAPTER V

EFFECT OF GLYPHOSATE CONCENTRATION IN THE DROP, DROP NUMBER AND SURFACTANT CONCENTRATION ON GLYPHOSATE PHYTOTOXICITY.

Drop characteristics such as drop size, herbicide concentration in the drop, drop number per unit area and surfactant concentration altered glyphosate phytotoxicity (1, 14, 24, 25, 29, 34, 41, 42, 47, 48, 59, 68).

In this study, glyphosate activity was evaluated when applied in 1 ul drops of various glyphosate concentrations, surfactant concentrations and number of drops per leaf.

MATERIALS AND METHODS

Effects of drop characteristics on thunbergia: Thunbergia seeds were scarified with a razor blade by scraping off part of the seed coat. They were soaked in water for 3 days, then they were planted in flats of vermiculite and allowed to germinate and grow. The seedlings were transplanted 8 weeks later into 10.2 cm diam. pots with 1:1 peat-vermiculite media. The plants were treated 4 weeks later. The pots were kept in the glasshouse at the Magoon Plant Science Laboratory, Honolulu, Hawaii. Photosynthetically active radiation was reduced by approximately 60%. Temperatures ranged from 18.9 to 42.2 ^{o}C. The experiment ran from March 15, 1982 (planting) to July 22, 1982 (regrowth shoot fresh weight harvest). The treatments consisted of 4 glyphosate (MON 0139) rates (0.0, 1.0, 2.0 and 4.0% w/w) with 4 surfactant (MON 0818) rates (0.0, 0.1, 1.0 and 10.0% w/w). The solutions were applied with 1 uL micropipettes at 1, 2 or 4 drops per leaf on the adaxial surface of both leaves of the second most fully expanded leaf pair of the main stem.

Visual ratings were made 2 weeks after treatment using the following rating scale: 1 = no injury; 2 = young leaves of the main (treated) stem were chlorotic, laterals were affected with chlorosis of the new foliage; 3 = young leaves and main apex were dead or dying, but lower stem was still green, older leaves appeared dehydrated, laterals were more severely affected with deformed and chlorotic young leaves, growth appeared halted; 4 = the main stem and foliage were dying or dead with plant tissue turning necrotic, laterals were severly affected with old and new leaves drying up, no growth; 5 = plant death. Shoot fresh weight was recorded 3 weeks after treatment and regrowth shoot fresh weight was recorded 6 weeks after treatment.

Effect of drop characteristics on guava: Guava (cv. 'Beaumont') seeds were planted in flats of vermiculite. Twenty weeks later they were transplanted in 10.2 cm diam. pots (1 plant per pot) using 1:1 peat-vermiculite media. The pots were kept in the glasshouse at the Magoon Plant Science Laboratory, Honolulu, Hawaii. Temperatures ranged from 18.9 to 42.2 ^{o}C. Photosynthetically active radiation was reduced approximately 60%. The experiment ran from September 19, 1981 (planting) to July 9, 1982 (regrowth shoot fresh weight harvest). The plants were treated 9 weeks after transplanting. The guava plants were approximately 13 to 20 cm tall at the time of treatment. Treatments were the same as for thunbergia. The solutions were applied with 1 uL micropipettes at 2, 4 or 8 drops per leaf on the adaxial surface of both leaves of the fourth leaf pair from the first fully expanded leaf pair. The experimental design was a randomized complete block with 5 replications.

Visual ratings were made 6 weeks after treament using the following rating scale: 1 = no injury, 2 = 1 or 2 leaf pairs affected, minimal tip burn and leaf crinkling, new growth at the terminal bud was not affected; 3 = several leaf pairs were affected with mostly leaf crinkling, marginal scorching and tip burn, however new growth at the terminal bud did not appear to be affected; 4 = leaf crinkling and curling becoming more prominent, internode growth was slightly affected; 5 = severely deformed young leaves, growth of young leaves and internodes severly inhibited, terminal bud dead or inhibited, axillary buds may have grown. Fresh weight of the new growth (tip portion above the fourth leaf pair from the treated leaves) was recorded 6 weeks after treatment and regrowth shoot fresh weight was recorded 10 weeks after treatment.

RESULTS AND DISCUSSION

Response of thunbergia to glyphosate concentrations, surfactant concentrations and number of drops: There was no 3-way interaction between glyphosate concentration in the drop, surfactant concentration and drop number for any of the parameters measured. Table 10 shows the results of glyphosate concentration and surfactant concentration treatments, averaged over drop number. The 2% w/w glyphosate rate with 1.0 and 10.0% w/w surfactant concentrations was more active by visual ratings than the 0% w/w surfactant concentration, and the 1.0% w/w surfactant concentration performed better than the 0.1% w/w surfactant concentration. Surfactant concentrations did not alter visual ratings at lower or higher glyphosate concentrations.

Shoot fresh weight data at the 2% w/w glyphosate concentration showed that the 1% w/w surfactant rate was more active in reducing fresh weight than the 0% w/w surfactant rate.

In the 2% w/w glyphosate treatment, regrowth was reduced by the 1% w/w surfactant rate as compared with the 0% w/w surfactant rate.

Increasing the surfactant concentration from 0 to 10% w/w did not increase glyphosate activity. However, the addition of surfactant increased glyphosate activity. This indicates that although addition of surfactant can increase glyphosate activity, there may be an optimum surfactant

Table 10.--Response of thunbergia to glyphosate and surfactant concentrations in the drop.[ab]

Treatment: Glyphosate Conc. (% w/w)	Treatment: Surfactant Conc. (% w/w)	Visual Ratings[c] 2 wk	Shoot Fresh Weight (g) 2 wk[d]	Regrowth Shoot Fresh Weight (g) 5 wk
0.0	0.0	1.0g	5.75ab	4.97ab
0.0	0.1	1.0g	6.50a	5.10ab
0.0	1.0	1.0g	6.43a	5.30ab
0.0	10.0	1.0g	6.89a	6.21a
1.0	0.0	1.7f	4.72bcd	4.90ab
1.0	0.1	1.8f	5.04bc	4.09bc
1.0	1.0	2.3ef	4.41cde	3.65bc
1.0	10.0	2.0ef	4.79bcd	5.07ab
2.0	0.0	2.3ef	4.06cdef	3.97bc
2.0	0.1	2.6de	3.36efg	2.84cd
2.0	1.0	3.2bc	2.56gh	1.82de
2.0	10.0	3.1cd	3.61defg	2.71cd
4.0	0.0	3.3abc	2.96fgh	1.34de
4.0	0.1	3.9a	1.87h	0.91e
4.0	1.0	3.7ab	2.15h	1.06e
4.0	10.0	3.8ab	2.02h	1.01e

[a]Within columns, values followed by the same letter are not significantly different at the 1% level according to Duncan's multiple range test.

[b]Values are averaged over drop number.

[c]Injury rating based on a scale of 1 = no injury and 5 = total death.

[d]Significant glyphosate conc. x surfactant conc. interaction.

concentration, where addition of more surfactant will not further enhance glyphosate activity. Therefore, the main limiting factor is glyphosate concentration. It has been shown that addition of surfactant to dilute glyphosate solutions increased herbicidal activity, but addition of surfactant to more concentrated glyphosate solutions did not (1, 26).

Table 11 shows data for glyphosate concentration in the drop and drop number, averaged over surfactant concentrations. An increase in herbicidal activity by applying the same amount of glyphosate in a more concentrated drop with less drops per leaf was shown by fresh weight data but not by visual ratings. The 4% w/w glyphosate concentration applied in 1-1 uL drop per leaf of the specified leaf pair reduced shoot fresh weight more than the 1% w/w glyphosate concentration applied in 4-1 uL drops. The shoot fresh weight data gave further evidence that the low volume-high concentrate glyphosate solution was more effective than the high volume-low concentrate glyphosate solution. It is possible that the high concentrate drops had a higher rate of diffusion into the leaf tissue, resulting in more glyphosate entering the leaf than the dilute glyphosate concentrate. Erickson and Duke (27) reported that ^{14}C-methyl glyphosate movement through the cuticle of quackgrass was linear with respect to time. Increasing the glyphosate concentration resulted in an

Table 11.--Response of thunbergia to glyphosate concentrations in the drop and drop number.[ab]

Treatment: Glyphosate Conc. (% w/w)	Treatment: Drop Number	Visual Ratings[c] 2 wk[d]	Shoot Fresh Weight (g) 2 wk[d]	Regrowth Shoot Fresh Weight (g) 5 wk[d]
0.0	1	1.0f	6.08ab	5.31a
0.0	2	1.0f	6.45a	5.83a
0.0	4	1.0f	6.65a	5.05a
1.0	1	1.6e	5.11bc	5.44a
1.0	2	1.9e	5.17bc	4.80a
1.0	4	2.4cd	3.93de	3.05b
2.0	1	2.0de	4.68cd	5.00a
2.0	2	2.6c	3.53ef	2.29bc
2.0	4	3.8b	1.98gh	1.22cd
4.0	1	2.7c	2.87fg	1.78bcd
4.0	2	3.9b	2.24gh	0.94cd
4.0	4	4.4a	1.63h	0.50d

[a]Within columns, values followed by the same letter are not significantly different at the 1% level according to Duncan's multiple range test.

[b]Values are averaged over surfactant concentrations.

[c]Injury rating based on a scale of 1 = no injury and 5 = total death.

[d]Significant glyphosate conc. x surfactant conc. interaction.

almost linear increase in movement of glyphosate across the cuticle. Also, surfactant concentration increases produced slight increases in glyphosate movement, but the increases were not different from each other.

The regrowth data did not show such significant differences as with the shoot fresh weight. In retrospect, the variability in assessing herbicidal activity of thunbergia to glyphosate made it a poor choice of a test species for this type of study.

Response of guava to glyphosate concentrations, surfactant concentrations and number of drops: There was no 3-way interaction between glyphosate concentration in the drop, surfactant concentration and drop number for any of the parameters measured. Table 12 shows data for the glyphosate concentration and surfactant concentration treatments, averaged over drop number. Only visual ratings showed a significant glyphosate concentration x surfactant concentration interaction. The 1% w/w glyphosate concentration with 10% w/w surfactant appeared to be more active visually than the 0, 0.1 and 1.0% w/w surfactant concentrations, and at the 2% w/w glyphosate concentration the treatments with 1.0 and 10.0% w/w surfactant added appeared more active than the 0 and 0.1% w/w surfactant concentrations. An anomaly occurred in the visual ratings at the 4% w/w glyphosate concentration. The 0.1% w/w surfactant concentration was less effective than the 0% w/w

Table 12.--Response of guava to glyphosate and surfactant concentrations in the drop.[a,b]

Treatment: Glyphosate Conc. (% w/w)	Treatment: Surfactant Conc. (% w/w)	Visual Ratings[c] 6 wk[d]	Shoot Tip Fresh Weight (g) 6 wk	Regrowth Shoot Fresh Weight (g) 10 wk
0.0	0.0	1.0d	7.70ab	3.24a
0.0	0.1	1.0d	7.89ab	3.87a
0.0	1.0	1.0d	7.37ab	3.56a
0.0	10.0	1.0d	6.04abc	3.51a
1.0	0.0	1.3d	7.15ab	3.71a
1.0	0.1	1.1d	8.07a	3.92a
1.0	1.0	1.6cd	7.21ab	3.59a
1.0	10.0	2.6ab	6.41abc	3.43a
2.0	0.0	1.7cd	6.67abc	3.44a
2.0	0.1	1.4cd	7.05ab	3.59a
2.0	1.0	2.7ab	7.31ab	3.45a
2.0	10.0	2.9ab	5.35bc	3.77a
4.0	0.0	3.2a	6.23abc	3.35a
4.0	0.1	2.1bc	7.06ab	4.01a
4.0	1.0	3.2a	5.43abc	3.43a
4.0	10.0	3.0a	4.48c	3.26a

[a]Within columns, values followed by the same letter are not significantly different at the 1% level according to Duncan's multiple range test.

[b]Values are averaged over drop number.

[c]Injury rating based on a scale of 1 = no injury and 5 = total death.

[d]Significant glyphosate conc. x surfactant conc. interaction.

surfactant rate.

The shoot tip fresh weight and the regrowth fresh weight data showed differences among main effects (glyphosate concentration, surfactant concentration and drop number), but there was no interaction between glyphosate concentration and surfactant concentration. Much of the differences observed in the visual ratings were not expressed in the shoot tip fresh weight data. The only difference occurred at the 4% w/w glyphosate concentration, the 10% w/w surfactant rate reduced fresh weight more than did the 0.1% w/w surfactant rate. However, there were no differences in the regrowth data, indicating that guava is tolerant to glyphosate.

Table 13 shows the results of glyphosate concentration and drop number, averaged over surfactant concentrations. Visual ratings showed that a 4% w/w glyphosate concentration applied in 4-1 uL drops to the leaves of the specified leaf pair injured guava more than the 2% w/w glyphosate concentration applied in 8-1 uL drops. However, there was no reduction in the shoot tip and regrowth data. Response to increasing amount of glyphosate did not level off at the 4% w/w glyphosate concentration, therefore higher glyphosate concentrations might have resulted in more treatment differences.

Table 13.--Response of guava to glyphosate concentrations in the drop and drop number.[ab]

Treatment			Shoot Tip Fresh Weight (g)	Regrowth Shoot Fresh Weight (g)
Glyphosate Conc. (% w/w)	Drop Number	Visual Ratings[c]		
		6 wk[d]	6 wk	10 wk
0.0	2	1.0f	7.32a	3.64ab
0.0	4	1.0f	7.53a	3.59ab
0.0	8	1.0f	6.91a	3.40ab
1.0	2	1.2ef	7.34a	3.44ab
1.0	4	1.6def	7.55a	3.86ab
1.0	8	2.1cd	6.74a	3.68ab
2.0	2	1.7de	7.11a	3.54ab
2.0	4	2.6bc	6.67a	3.62ab
2.0	8	2.1cd	6.00ab	3.53ab
4.0	2	2.1cd	6.84a	4.16a
4.0	4	2.9b	6.04ab	3.40ab
4.0	8	3.6a	4.53b	2.98b

[a]Within columns, values followed by the same letter are not significantly different at the 1% level according to Duncan's multiple range test.

[b]Values are averaged over surfactant concentrations.

[c]Injury rating based on a scale of 1 = no injury and 5 = total death.

[d]Significant glyphosate conc. x drop number interaction.

CHAPTER VI

CONCLUSIONS

In the low volume applicator study, the wiper applicator gave the best overall weed control. This was probably the result of better coverage and the higher glyphosate concentrations used. However, the manner in which each of these applicators was used might not have been the most efficient way to use them. The method of application in the low volume applicator study was similar to using conventional spray equipment, where a constant walking speed was established for a given distance. This method was sufficient for the wiper applicator, but was probably not efficient for use with the brush and Magicwand applicators as inadequate coverage was provided. With adequate coverage, these applicators would probably have been just as effective as the wiper applicator, but a slower application time would result.

These applicators would probably provide optimal results in different situations. The brush applicator would be ideal for spot treatments in and around the field. The Magicwand could also be used for spot treatments, and also for border weed control, as the slightly pressurized sprayer can deliver a solid stream of herbicide solution several meters. However, these applicators may not be efficient where weed density is rather high (eg. 333 nutsedge plants/m^2), as adequate coverage may be a problem. The wiper applicator could be used in most situations, except in areas that are hard to reach. Weed density should not be a great concern provided the weeds are not too large. Care should also be taken not to soil the absorbant material on the wiper applicator as soil has been shown to render glyphosate inactive (60, 61).

Glyphosate applied with the low volume applicators, in most cases, showed equal or better activity than the conventional application method. The diluent volume study showed that low volume-high concentrate glyphosate solution was more active than the high volume-low concentrate solution with most weed species except for guava, which was the most tolerant species. Further experimentation with the drop study also showed this trend on thunbergia. The drop study did not show a constant increase in glyphosate activity with increasing surfactant concentrations, however, the presence of surfactant did increase glyphosate activity. Hence, the herbicide concentration in the drop (spray) could be the more important limiting factor for increased glyphosate activity.

It has been reported that the rate of diffusion of glyphosate increases with increasing glyphosate concentration (27). Hence, this may have an effect on glyphosate activity especially at the lower rates. The total amount of glyphosate entering the plant would be greater in one concentrated drop than several dilute drops over a given period of time, even though the total amount of glyphosate applied to the plant was the same. Therefore, at threshold levels of glyphosate, the extra glyphosate entering the plant due to the higher herbicide concentration in the drop, could have been the difference between good weed control with no regrowth and moderate weed control with some regrowth.

Important economic implications arise as a result of the findings in these studies. The use of glyphosate in low volume applicators can be very effective in controlling weeds. A high degree of selectivity by placement can be obtained with this non-selective herbicide. Drift is minimal or none at all, therefore yield losses due to drift and misdirected sprays should be eliminated. The particular design of the wiper and brush applicators can be altered to suit the needs of the user and the possible modifications are limited only by the ingenuity of the user. Another cost-saving factor is that the total amount of herbicide used per given area is reduced even though the glyphosate concentrations are higher.

The use of low volume applicators (eg. ropewick applicator) is quite popular as indicated by the many research articles that have been written over the past few years and the rapid adoption by the American farmer. However, further work needs to be done in the area of how glyphosate activity is affected by drop characteristics, environmental conditions and growth stage of the weed, as all of these factors appear to have considerable influence on glyphosate activity.

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